EL Program: Earthquake Risk Reduction in Buildings and Infrastructure

Program Manager: John R. Hayes, Jr., 301 975 5640

Strategic Goal: Disaster-Resilient Buildings, Infrastructure, and Communities

Summary: The objective of this program is to develop and deploy advances in measurement science related to earthquake engineering, including performance-based tools, guidelines, and standards for designing buildings to resist earthquake effects, improve building safety, and enhance disaster resilience. The program fulfills the NIST applied research role in the statutory four-agency National Earthquake Hazards Reduction Program (NEHRP)[i] and involves in-house and extramural research concentrated in five major areas: technical support for building code development, performance-based seismic engineering, national design guideline development, evaluated technology knowledge dissemination, and evaluation and strengthening for existing buildings. The program also includes the statutory NIST role as the NEHRP Lead Agency to coordinate the research and implementation activities of the four NEHRP agencies – the Federal Emergency Management Agency (FEMA), NIST, the National Science Foundation (NSF), and the United States Geological Survey (USGS).

DESCRIPTION

Objective: The objective of this program is to develop and deploy advances in measurement science related to earthquake engineering, including performance-based tools, guidelines, and standards for designing buildings to resist earthquake effects, improve building safety, and enhance disaster resilience of buildings, infrastructure, and communities by 2016.

What is the problem? The problem extends from widespread earthquake hazards and associated risk in the built environment, to a lack of comprehensive, full-spectrum research, implementation, and outreach.

Damaging earthquakes are infrequent, but have essentially no warning, creating potentially catastrophic consequences. Major 2010 and 2011 earthquakes in Haiti, Chile, New Zealand, and Japan re-emphasized the potential impacts of such events. During U.S. recorded history, earthquakes of magnitude 6.5 (M6.5) or greater have occurred in Alaska, California, the Pacific Northwest, South Carolina, the Intermountain West, the Central U.S., and New England.

A 2003 Earthquake Engineering Research Institute (EERI) report[ii] stated that a single large earthquake in a major U.S. urban area could easily cause direct and indirect economic losses

between $100B and $200B[iii]. The report also noted that economic and population growth, accompanied by increased societal interconnectedness that is largely due to increased urbanization, has led to greatly increased numbers of people and extent of infrastructure at risk. The report also explained that U.S. model building codes emphasize occupant ***life safety***, with little consideration given to economic losses or rapid recovery. This was early recognition that earthquake preparedness should extend to providing local, state, and national earthquake ***resilience***[iv].

The NEHRP agencies cast a vision of a disaster-resilient nation in the NEHRP Strategic Plan[v], and the present Administration has recognized that national resilience in the face of risks from hazards is a vital challenge[vi]. The National Research Council endorsed the NEHRP vision in its 2011 report[vii] and stated that "*A disaster-resilient nation is one in which its communities, through mitigation and pre-disaster preparation, develop the adaptive capacity to maintain important community functions and recover quickly when major disasters occur*."

While seismic design provisions for new buildings in U.S. model building codes have been improved, their continued focus is on occupant life safety using costly, inflexible prescriptive design procedures. The typical code-compliant building may withstand the effects of moderate earthquakes but will likely be severely damaged when subjected to larger events, leading to costly repair work, or demolition and replacement, and severely limiting resilience. The nation's existing building stock is more vulnerable to earthquake damage than newly designed buildings, posing even higher societal risk, both in terms of life safety and resilience. Cost-effective seismic evaluation and mitigation methodologies for them are not widely available or applied.

Basic earthquake engineering research that is supported by the National Science Foundation (NSF) is not linked closely with the efforts of the Federal Emergency Management Agency (FEMA) to assist in developing earthquake provisions of national model building codes and standards. A 2003 Applied Technology Council (ATC) report identified this technology transfer "gap" as a serious national deficiency[viii] that hampers transferring new technologies into design and construction. The gap is manifested in a lack of measurement science in several key areas, for both new and existing buildings, including accurate and cost-effective seismic analysis and design procedures that support existing prescriptive standards, rigorous performance-based assessment procedures that support performance-based seismic engineering, and experience-based guidance for earthquake-resistant building designs.

Why is it hard to solve? The research, implementation, and outreach needed to improve national earthquake resilience requires integrating the coordinated diverse but complementary capabilities of at least the four NEHRP agencies. These capabilities include seismic monitoring, mapping, and notification (USGS); education and basic research in earth sciences, social sciences, and earthquake engineering (NSF); applied earthquake engineering research (NIST); and knowledge transfer into national model building codes and to practitioners (FEMA). The agencies have distinct cultures, leadership, funding, and constituencies.

Experimental data on the earthquake performance of structures and their component assemblies from initial response to failure are limited. The complexity of nonlinear structural analysis software continues to make it complex to use properly, and the softwared remains highly susceptible to numerical instabilities. Due to these shortcomings in nonlinear analysis

capabilities and the lack of validating experimental or experiential data, earthquake engineering practitioners lack standard, accurate, and efficient methods of predicting, evaluating, and assessing the disaster resilience of structures. Performance-based seismic engineering (PBSE) techniques that provide more cost-effective earthquake performance of structural systems and the opportunity for enhanced resilience are often much more complex than the prescriptive procedures that dominate building codes, standards, and practices. Many of the prescriptive provisions are conservatively based on "engineering judgment," without the support of research data. The lack of major U.S. earthquake experience since 1994, while fortunate for society, limits the first-hand expertise of earthquake practitioners in all disciplines.

The earthquake-resistant designs and dynamic responses of buildings and other structures to earthquake-induced ground motions, as well as localized geotechnical conditions (*e.g.*, soil liquefaction), are thus not well understood by many design professionals, standards developers, urban planners, and emergency planners. On a broader scale, communities lack standard methods of assessing their disaster resilience for use in making preparedness and mitigation decisions.

How is it solved today, and by whom? Since becoming the NEHRP Lead Agency (2006), NIST has actively partnered, coordinated, and managed NEHRP activities with FEMA, NSF, and USGS. The most recent authorizing legislation, Public Law (PL) 108-360[ix], expired at the end of FY 2009. Reauthorization hearings were conducted by the U.S. House of Representatives in June 2009 and again in April 2011. Reauthorization bills were introduced (HR 3479[x] and S 646[xi]) in the 112th Congress but have not been passed.

The problem of providing effective performance-based design tools and guidance, and model building codes and standards that support societal resilience is not solved today. Within NEHRP, the primary NIST role beyond that of providing overall NEHRP leadership is linking the basic research products from NSF-supported research with the model building codes and standards development work that is supported by FEMA ("bridging the gap" that has been cited by ATC and others). Prior to FY 2007, NIST STRS appropriations had not addressed fulfilling this applied research need for more than a decade. No other agency satisfies this need, though FEMA and NSF fulfilled the role on an *ad hoc* basis as effectively as they could without NIST support. The 2008 NEHRP assessment by the NEHRP Advisory Committee on Earthquake Hazards Reduction[xii] noted that "a number of (NIST) statutory responsibilities have not been met because of a lack of funding."

Why NIST? Under NEHRP, NIST has specific statutory roles to fulfill. PL 108-360 directed that NIST be established as the NEHRP Lead Agency, with responsibility for program coordination and planning, and makes NIST responsible for performing applied earthquake engineering research.

In addition to fulfilling statutory requirements, this program supports the NIST EL mission of promoting U.S. innovation and competitiveness by anticipating and meeting measurement science, standards, and technology needs of the U.S. building and fire safety industries in ways that enhance economic security and improve the quality of life. It also supports the EL core

competency in resilience and reliability of structures subjected to multi-hazards, and provides knowledge transfer that is not well-supported by the fragmented U.S. construction industry.

What is the new technical idea? NIST EL supports the statutory NEHRP Lead Agency responsibility, which includes supporting the NEHRP Interagency Coordinating Committee (ICC), the senior leadership body for NEHRP; drafting and updating NEHRP strategic and management plans; developing coordinated interagency budgets; submitting annual reports on NEHRP activities; and, supporting the Advisory Committee on Earthquake Hazards Reduction (ACEHR).

Through this engagement in NEHRP, NIST has developed broad technical goals for its earthquake-related research. The NEHRP agencies developed the 2009-2013 NEHRP Strategic Plan[xiii], which provides a coordinated NEHRP-wide approach to research and implementation. The Plan establishes a national vision for *a nation that is earthquake-resilient in public safety, economic strength, and national security*. The Plan established nine strategic priorities for the NEHRP agencies to pursue, depending on the availability of future resources. In 2011, the National Research Council (NRC) completed a NIST-commissioned study for NEHRP that produced a twenty-year "roadmap" for earthquake resilience research, implementation, and outreach[xiv]. The roadmap endorsed the NEHRP Strategic Plan and provides a comprehensive perspective that was developed by leading North American earthquake professionals.

NIST EL research planning focuses on activities that are needed to fulfill its responsibilities as outlined in the Strategic Plan and the NRC roadmap. These responsibilities are outlined philosophically in the 2003 NIST earthquake R&D program plan provided by ATC 57[xv]. Since 2006, individual research projects have conformed to the ATC 57 philosophy and satisfied needs that have been delineated by leading earthquake engineering practitioners and researchers in various national publications. All projects have been validated through interactions with engineers who are actively developing national standards for seismic design, primarily ASCE/SEI 7[xvi]. Moving to a more long-range focus, NIST commissioned the Building Seismic Safety Council (BSSC) to develop a ten-year research roadmapping effort for NIST-specific research that supports the ATC 57 philosophical goals and the broad research directions set by the NRC study. This new roadmap is being developed nationally by prominent structural and geotechnical engineers with both research and practitioner expertise. Work on this new roadmap included a May 2012 workshop that BSSC conducted. Preliminary results from that workshop were considered in formulating the 2013 program.

The common thread through these planning activities is resilience. The significant new idea is that earthquake resilience can be enhanced significantly by developing robust capabilities to predict and mitigate effects of earthquakes on complex building systems and on communities-at-large. Resilience will be achieved by developing validated: (1) *data* to characterize the risk environment; (2) physics-based *models* to predict performance of structures to failure; (3) *metrics* for measuring performance; (4) acceptance *criteria* for different performance objectives; (5) *mitigation* strategies based on evaluated performance; and, (6) community-scale loss estimation *tools*.

Why can we succeed now? Across NEHRP, success is anticipated because of the significant synergy that exists among the four NEHRP agencies. The Strategic Plan was developed collegially by the four agencies, considering their capabilities and the needs of the nation. The NIST Lead Agency role and the program activities are also strongly supported by the ICC and the ACEHR. The ICC includes the administrator/directors of the four NEHRP agencies, as well as the directors of the White House Office of Management and Budget (OMB) and Office of Science and Technology Policy (OSTP). It provides unduplicated senior leadership synergy. The ACEHR provides valuable insights from leading practitioners and researchers that facilitate improved planning and interaction.

EL is implementing the ATC 57 R&D research philosophy. The soon-to-be-released BSSC roadmap for NIST research will ensure that NIST focuses on issues of national consensus high priority. Supporting this approach, recent advances in earthquake-related technical disciplines and computational capabilities make possible significant advances in the component research topics.

The ATC 57 report also included a recommendation that NIST continuously engage the earthquake engineering research and practitioner communities in its activities, to ensure effective knowledge transfer into and out of NIST. To implement this, NIST R&D is being performed through a partnership of core in-house and world-class extramural expertise. The contractor partnership, which is provided through an indefinite delivery – indefinite quantity (IDIQ) contract, affords EL access to leading U.S. earthquake researchers and practitioners within essentially all required technical disciplines; for example, ongoing contracted efforts that are tied to geotechnical engineering would not be possible with the in-house structural engineering staff. In 2007, NIST awarded a five-year IDIQ contract to the NEHRP Consultants Joint Venture[xvii] (NCJV) that taps practitioner, analytical and experimental research expertise, and includes interaction with researchers and facilities associated with the NSF-sponsored George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES). In 2013, this IDIQ contract will be re-competed nationally.

What is the research plan? As described above, there is a hierarchy of planning documents that have already been or will be developed, starting broadly with the NEHRP Strategic Plan[xviii], which has three strategic goals, each having four or five major objectives, and nine strategic priorities for program activities that deserve increased emphasis if resources are available to support them. The NRC roadmap provides expert recommendations on research, implementation, and outreach activities for the four agencies, consistent with the Strategic Plan, that should be undertaken over the coming twenty years for the nation to achieve the vision of earthquake resilience presented in the NEHRP Strategic Plan. Based on the NRC roadmap recommendations and other specific planning documents that have been developed for the NEHRP agencies, NIST has retained BSSC to provide national consensus planning for NIST earthquake engineering research that will fulfill prioritized near-term (less than three years) needs; mid-term (3-5 years) needs, and longer-term (5-8 years) needs. This will facilitate future (FY 2014 and beyond) research planning that is strategic in nature and based on well-informed expert opinion.

For 2013, the ATC 57 philosophy, augmented by knowledge that is being developing in the BSSC roadmapping study, has informed project planning. The program consists of six thrusts,

five of which are research thrusts and one of which is tied to the NEHRP Lead Agency role for NIST:

(1) National Earthquake Hazards Reduction Program (NEHRP) Coordination: This thrust includes all administrative and management activities to perform the NEHRP Lead Agency role. This includes support for all activities of the Interagency Coordinating Committee (ICC), the Advisory Committee on Earthquake Hazards Reduction (ACEHR), interagency program coordination via the Program Coordination Working Group, required reporting (*e.g.*, NEHRP Annual Report), and routine knowledge transfer activities (*e.g.*, NEHRP web site). Two extramural Lead Agency activities that were funded in 2012 will proceed: develop a lifelines research, implementation, and outreach roadmap for the entire program via a national workshop and study; and develop initial outlines for future reorientation of the coordination of NEHRP post-earthquake reconnaissance and data management activities. NIST will host an international meeting in February 2013 of the U.S.-Japan Cooperative Program in Natural Resources (UJNR) Panel on Wind and Seismic Effects and continue its work as the U.S.-side chair of the Panel. NIST will also continue its support for the Interagency Committee on Seismic Safety in Construction (ICSSC).

(2) Further develop Seismic Analysis and Design Procedures in Existing Standards: This thrust is consistent with the ATC 57 program element of *Technical Support for Building Code Development*[xix] and seeks to develop physics-based *models* to predict performance of structures to failure. This research consists of short-term practical, applied research projects that improve seismic design practice and building code development. National model building codes contain prescriptive seismic provisions that have largely evolved from practitioner experience, without specific research results to substantiate them, but which will certainly form the basis for seismic design for most U.S. buildings for the foreseeable future. EL will continue two in-house elements that were begun in 2011:

- Develop improved simplified modeling of the effects of vertical and horizontal structural irregularities and of higher response mode effects in mid-rise and taller buildings. This research will analyze field observations of buildings made following the 2010 Chile earthquake, using both simplified and nonlinear dynamic models of those buildings, to develop candidate improved prescriptive provisions that will migrate those U.S. standards to become more performance-based.

- Develop tools to facilitate seismic design of buildings in the eastern U.S., for which wind loading is also a significant consideration. Wind load design may create a degree of robustness in certain structural systems that will permit ductility requirements for seismic design to be relaxed, thus saving construction costs without sacrificing safety.

The NEHRP Consultants Joint Venture (NCJV) is completing three extramural projects in 2013 that also address analysis and design procedures in existing standards but involve no 2013 funds: *Improved Structural Response Modification Factors for Seismic Design of New Buildings, Phase I*; *Cost-Benefit Analysis of Codes and Standards for Earthquake-Resistant Construction in Selected U.S. Regions, Part I*; and, *Use of High Strength Reinforcement in Reinforced Concrete Seismic Design*. Those efforts are described in pre-2013 project descriptions.

(3) Develop improved Lateral Force-Resisting Structural Elements and Systems: This thrust is consistent with the ATC 57 program element of *Problem-Focused Research and Technical Resources Development to Improve Seismic Engineering Practice* and again seeks to develop physics-based *models* to predict performance of structures to failure. The elements of this thrust all involve performing and analyzing laboratory test data. EL will continue two in-house elements that were begun in 2012 and support a third, smaller one-year 2013 effort:

- Develop global and local buckling models and improved concepts of inelastic stability for axially-loaded deep, slender wide-flange steel sections, such as those used for lower-story columns in mid-rise buildings in seismically active areas. This work was identified as an area of major research need by an extramural panel of experts in NIST GCR 11-917-13[xx]. In-house analytical studies in this element will complement an extramural laboratory testing ATC task order that was funded in the 2012 program.

- Develop more accurate analytical modeling techniques and more ductile construction detailing procedures for reinforced concrete (R/C) walls. This work was precipitated by field observations of buildings damaged in the 2010 Chile earthquake that showed that current R/C wall construction details may limit their ductility during earthquake-induced motions. This effort will assimilate and analyze experimental data from tests that will be performed in a 2012 extramural-funded effort at the U.S. Army Engineer Research and Development Center (ERDC) Construction Engineering Research Laboratory (CERL).

- Develop design guidelines for cold-formed steel (CFS) shear panels for use in low-rise commercial construction. CERL performed extensive laboratory testing of CFS shear panels but was never able to publish the research data. This element will support analysis of the data and publishing it in a form that will provide design guidelines useful for structural engineers.

(4) Perform Assessment of Design Methods in Existing Performance-Based Seismic Design (PBSD) Standards: This thrust is consistent with the ATC 57 program element of *Develop the Technical Basis for Performance-Based Seismic Engineering* (PBSE) and focuses on developing *metrics* for measuring performance and acceptance *criteria* for different performance objectives. Since PBSE relies on a detailed understanding of the nonlinear behavior of buildings, other structures, and non-structural elements to failure, both basic and problem-focused research are needed to complement the input of practitioner knowledge. A 2008 NEHRP workshop produced a research and implementation needs report[xxi] that guides planning in this area. This element benchmarks prevailing current PBSE methodology, which applies ASCE 41[xxii] analysis procedures that were developed for existing buildings to new buildings. There are separate parallel research efforts in structural steel and reinforced concrete (R/C). Work in this area was cited as the highest performance-based seismic design (PBSD) research need in NIST GCR 09-917-2.

(5) Develop Performance-Based Seismic Engineering (PBSE) for New Buildings: This thrust is also consistent with the ATC 57 program element of *Develop the Technical Basis for Performance-Based Seismic Engineering* (PBSE) and focuses on developing *metrics* for measuring performance and acceptance *criteria* for different performance objectives. This thrust will develop collapse simulation capabilities through quantifying collapse demand and capacity directly with improved analytical capabilities, and provide clear and succinct guidelines on

collapse assessment methodologies. Structural collapse demand and capacity are not clearly defined or directly simulated in current Performance-Based Seismic Engineering (PBSE) methodology, resulting in a critical gap in structural collapse assessment accuracy. Work on this element is anticipated to be performed extramurally under the umbrella of a new multi-year IDIQ contract that will be awarded in 2013.

Several ongoing extramural projects providing PBSE support will be completed in 2013 but involve no 2013 funds. These projects include *Improved Procedures for Characterizing and Modeling Soil-Structure Interaction for PBSE*; *Analysis, Modeling, and Simulation for PBSE*; and *Development of a Collapse Indicator Methodology for Existing RC Buildings*. Those efforts are described in previous year project descriptions.

(6) Develop Techbrief Guidance for Evaluated Technologies: This ATC 57-recommended research area involves developing synthesis documents, known as *techbriefs*, that distill research findings, findings of professional committees and task groups, and cost-effective and code-compliant detailing practices into forms usable by practitioners. The *techbrief* thrust develops *mitigation* strategies based on evaluated performance. EL develops candidate techbrief topics in consonance with the earthquake practitioner community, based both on need and maturity of source information. *Techbriefs* are being produced extramurally at the rate of one or two per year. New *techbriefs* on seismic design of special reinforced masonry shear walls and seismic design of steel special eccentric braced frame systems will be developed in 2013.

How will teamwork be ensured? At the program leadership level, NEHRP is a partnership of the four NEHRP agencies (FEMA, NIST, NSF, and USGS), which have developed a strong working relationship. The NEHRP ICC ensures that NEHRP communications, and subsequent major decisions, occur at the agency administrator/director level, and that OMB and OSTP are involved. In addition, at the encouragement of the ACEHR, NEHRP reaches out to other federal agencies that have earthquake-related missions (*e.g.*, FHWA). Within the NEHRP partnership, NIST works particularly closely with FEMA. In addition, the extramural contracting process affords access to leading researchers and practitioners around the nation.

As the research program's component projects are formulated, appropriate collaborations with fellow researchers in the Materials and Structural Systems Division, the Fire Research Division, the Applied Economics Office, the Statistical Research Division and Mathematical and Computational Sciences Division (ITL) will be utilized.

What is the impact if successful? Tools, knowledge, standards, education, and outreach provided by NEHRP will significantly enhance earthquake resilience of the nation's communities and built environment. NEHRP research and implementation efforts will result in reduced societal risk, cost, and operational impacts from earthquakes on individuals, businesses, and government. The program will also foster a transformation from prescriptive to performance-based design codes and standards, enabling innovation in materials, technologies, and system designs and fostering cost-effectiveness. This will help solidify the U.S. economy and enhance the U.S. construction industry's international competitiveness.

Many key stakeholders have interests in the outcomes of this program: at-risk communities and the American public; governments at all levels that are responsible for mitigation and for

response, recovery, and rebuilding in the aftermath of catastrophic disasters; design and construction practitioners; facility owners and operators; national standards and model building code developers; state and local building officials; and property risk insurers. NEHRP has been strongly endorsed in recent communications to Congress by the American Society of Civil Engineers (ASCE), the Earthquake Engineering Research Institute, and the NEHRP Coalition.

The primary measure of successful impact in the earthquake engineering research arena is incorporation of results in ASCE's *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7[xxiii]. The adoption of new standards provisions in ASCE/SEI 7 is a multi-step, multi-year process, beginning with FEMA's well-established program of working with the Building Seismic Safety Council (BSSC) Provisions Update Committee (PUC) to develop new recommended model building code provisions that are considered for adoption by ASCE and, in turn, the International Code Council. These "recommended provisions" are periodically published as the NEHRP *Recommended Seismic Provisions for New Buildings and Other Structures*, most recently released in 2009[xxiv]. These "recommended provisions" are then directly considered by the ASCE as it periodically releases ASCE/SEI 7. The last edition of ASCE/SEI 7 was released in 2010, and the previous edition was released in 2005; the next edition is planned for 2016. With life safety "on the line," the structural engineering profession moves slowly and deliberately in considering new standards provisions. Since the current NIST Earthquake Risk Reduction in Buildings and Infrastructure program got underway on a modest level in 2007, research results have been reported too late for consideration in the process that led to the 2010 edition of ASCE/SEI 7.

However, a significant number of NEHRP Consultants Joint Venture (NCJV) task order outputs are currently being used in BSSC PUC and ASCE/SEI 7 Seismic Subcommittee deliberations regarding new proposed standards provisions that are being considered for ASCE/SEI 7's update in 2016. Following is a brief summary of known activities in the combined BSSC PUC and ASCE/SEI 7 arenas:

- Task Orders 1 and 4 were combined in project ATC 76, which produced NIST GCR 10-917-8, *Evaluation of the FEMA P-695 Methodology for Quantification of Building Seismic Performance Factors*. The report is being referenced by the BSSC PUC to develop proposed modifications to Chapter 16 in ASCE/SEI 7.

- Task Order 6, also a part of ATC 76, produced NIST GCR 10-917-9, *Applicability of Nonlinear Multiple-Degree-of-Freedom Modeling for Design*, is being referenced by the BSSC PUC to develop proposed modifications to Chapter 16 in ASCE/SEI 7, and is also being sourced by be used to update the Non Static Analysis provisions in the pending update of ASCE 41, *Seismic Rehabilitation of Existing Buildings*.

- Task Order 9, via project ATC-82, produced GCR 11-917-15*, Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analyses*. This report is being referenced by the BSSC PUC to develop proposed modifications to Chapter 16 in ASCE/SEI 7. The report is also referenced in the FEMA P-58 methodology for next generation performance assessment of buildings.

- Task Order 10, via project ATC 83, has produced draft GCR 11-917-14, *Soil-Structure Interaction for Building Structures*. The information contained in the draft report is already being considered by the BSSC PUC for defining risk-based performance objectives in Chapter 19 of ASCE/SEI 7 and is being considered for its applicability to updated provisions in ASCE 41.

- Task Order 11, via project ATC 84, has produced draft GCR 12-917-20, *Tentative Framework for Development of Advanced Seismic Design Criteria for New Buildings*. The information contained in the draft report is already being considered by the BSSC PUC for defining risk-based performance objectives in ASCE/SEI 7.

In addition to the above-cited impacts on new building design standards, Task Order 5, also a part of ATC 76, produced NIST GCR 10-917-7, *Program Plan for the Development of Collapse Assessment and Mitigation Strategies for Existing Reinforced Concrete Buildings*. This GCR has been used to guide FEMA-funded projects on the identification and mitigation of older existing non-ductile concrete buildings. Its results are also being studied by the American Concrete Institute (ACI) Committee 369 on Seismic Repair and Rehabilitation and by the ASCE Standards Committee 41 on Seismic Evaluation and Rehabilitation.

Of the products thus far released, and given that the above-mentioned standards activities are still evolving, the seven techbriefs have made the largest collective impact – they are mentioned in the Accomplishments section below. The techbriefs primarily target the practitioner community, provided practicing engineers with succinct summaries of the current states of practice in targeted topic areas. The techbriefs have come into widespread use in design offices and also are used in graduate level structural engineering classes. In 2011, the National Council of Structural Engineers Associations (NCSEA) conducted a four session webinar series based on the first four techbriefs. Techbriefs are included in the commentaries for the new editions of the NEHRP Recommended Provisions, ASCE/SEI 7, and the AISC Seismic Provisions and Design Manual.

What is the standards strategy? NIST is responsible for performing applied research, development, and knowledge transfer activities that link NSF-supported basic research and other products to FEMA's codes and standards efforts. FEMA has the above-described program with the BSSC PUC that in turn works very closely with the ASCE/SEI 7 Subcommittee on Seismic Loads (also described above). The ASCE Standard is then cited by direct reference in the *International Building Code*, which is promulgated by the International Code Council. This process is described in some detail in a recent NEHRP Seismic Waves article[xxv].

To ensure full consideration of NIST research outputs, NIST engineers are members of the BSSC PUC and of the ASCE/SEI 7 Subcommittee on Seismic Loads, so knowledge and technologies developed at NIST may be considered directly. This also gives NIST insight and oversight on the seismic standards development process.

NIST engineers also participate in the ASCE 41 committee that develops standards for evaluating and strengthening existing buildings[xxvi], so interactions similar to those for new buildings standards occur. NIST engineers participate in the relevant technical committees of the

ACI and the American Institute of Steel Construction (AISC) where material-specific standards issues concerning seismic performance are addressed. ACI and AISC codes and standards are in turn referenced by the IBC.
It is also important to note that much of the above-mentioned impact areas resulted from having nationally prominent researchers and practitioners engaged with contract task orders. These same engineers work on the BSSC and ASCE committees that are responsible for standards development, so that many more engineers than just those who are NIST employees are engaged in the NIST standards strategy.

The combined participation of NIST engineers and these other leading practitioners and researchers is ensuring that the NIST research products are being actively considered in appropriate provisions of the new standards provisions that are under development – the testament to this is in the list of specific impact areas that is shown above.

The new NIST EL policy is to list the "top 5" standards development needs in the Standards Strategy section. With the 2013 completion of the NIST NEHRP roadmap by the BSSC, a practitioner-endorsed list of top priorities will be available for the 2014 Program Description.

How will knowledge transfer be achieved? Knowledge transfer will largely be accomplished through the well-established NEHRP mechanism. NIST is responsible for performing applied research, development, and knowledge transfer activities that link NSF-supported basic research and other products to FEMA's implementation activities. As described in the previous section, FEMA works through the BSSC to develop new recommended model building code provisions that are considered for adoption by ASCE and, in turn, the International Code Council. EL will also develop and disseminate guidance and tools that assess and reduce building vulnerabilities, and produce recommended cost-effective changes in national model building codes, practices, and standards. Thus far, all research projects are being documented via at least one major report per project. In addition, major efforts are being made to ensure that public presentations of the products that result from these projects are presented in public and peer-review fora. Finally, as mentioned above, key research results are already being considered for adoption in national standards documents – this practice will continue.

MAJOR ACCOMPLISHMENTS

Outcomes: The NEHRP Secretariat was created at NIST in 2006, and the EL Earthquake Risk Mitigation R&D Program was re-started in 2007, following a period of relative inactivity.

The NEHRP Interagency Coordinating Committee (ICC) met initially in April 2006 and has now met a total of eleven times, providing program guidance from agency administrator/directors. The NEHRP Advisory Committee on Earthquake Hazards Reduction (ACEHR) was formed in mid-2007 and has met at least twice annually since (combination of face-to-face and teleconference meetings). The ACEHR has provided annual assessments on the program to the NIST Director in 2008, 2009, 2010, 2011, and 2012. At the working level, the NEHRP Program Coordination Working Group (PCWG) meets approximately monthly. The 2006 - 2011 annual reports have been released.

The NEHRP Strategic Plan was released in October 2008[xxvii]. In March 2011, the NRC produced for NEHRP a twenty-year roadmap of all research and implementation activities needed to support improved national earthquake resilience[xxviii]. The NRC roadmap fully endorsed the Strategic Plan.

NEHRP has sponsored several researcher-practitioner workshops to assist in scoping strategic priorities that were identified in the Strategic Plan: research and implementation issues related to existing buildings (September 2007); research and implementation issues related to Performance-Based Seismic Design (May 2008); developing a Post-Earthquake Information Management System (July 2008); and developing and performing earthquake scenarios (September 2008). Comprehensive reports have been produced for three of the four workshops: existing buildings[xxix], performance-based seismic design[xxx], and Post-Earthquake Information Management System[xxxi]. The Earthquake Engineering Research Institute (EERI) has created a scenario information and guidelines web site, based on the fourth workshop[xxxii].

NEHRP activated the first generation of the "NEHRP Document Clearinghouse," where all NEHRP-related documents available through the National Technical Information Service (NTIS) are available on-line at no cost to the user[xxxiii].

In June 2008, the NEHRP Director led a U.S. delegation to China for discussions with representatives of the China Earthquake Administration (CEA) regarding the 2008 Wenchuan earthquake and future research cooperation. Following this, NIST, NSF, and USGS, working jointly as NEHRP partners, signed a new earthquake-related protocol with the China Earthquake Administration (CEA) and National Natural Science Foundation of the People's Republic of China (PRC). In December 2011, the NEHRP agencies hosted a visit by a delegation from the CEA Institute of Engineering Mechanics.

In June 2009 and April 2011, the NEHRP Director testified on behalf of the NEHRP agencies at the NEHRP reauthorization hearing, which was conducted by the Subcommittee on Innovation and Technology, Committee on Science and Technology, U.S. House of Representatives.

The NEHRP Director re-initiated activities of the federal Interagency Committee on Seismic Safety in Construction (ICSSC). In December 2011, NEHRP worked with the ICSSC member agencies to update the *Standards of Seismic Safety for Existing Federally Owned or Leased Buildings*[xxxiv].

The NEHRP Director re-initiated the formal bilateral relationship of the U.S.-Japan Cooperative Program on National Resources Panel on Wind and Seismic Effects, with two meetings in 2011 (San Francisco, Tsukuba).

Outputs:

Seven techbriefs have thus far been produced:

- *Seismic Design of Reinforced Concrete Special Moment Frames: A Guide for Practicing Engineers*, NIST GCR 08-917-1;

- *Seismic Design of Steel Special Moment Frames: A Guide for Practicing Engineers*, NIST GCR 09-917-3;

- *Seismic Design of Cast-in-Place Concrete Diaphragms, Chords, and Collectors: A Guide for Practicing Engineers,* NIST GCR 10-917-4;

- *Nonlinear Structural Analysis for Seismic Design: A Guide for Practicing Engineers,* NIST GCR 10-917-5;

- *Seismic Design of Composite Steel Deck and Concrete-Filled Diaphragms: A Guide for Practicing Engineers,* NIST GCR 11-917-10;

- *Seismic Design of Cast-in-Place Concrete Special Structural Walls and Coupling Beams: A Guide for Practicing Engineers,* NIST GCR 11-917-11REV-1; and,

- *Seismic Design of Reinforced Concrete Mat Foundations: A Guide for Practicing Engineers,* NIST GCR 12-917-22.

Several other reports have recently been produced:

- *Evaluation of Contemporary Design of Reinforced Concrete Lateral Resisting Systems Using Current Performance Objective Assessment Criteria*, NISTIR 7766;

- *Concrete Model Building Subtypes Recommended for Use in Collecting Inventory Data*, NIST GCR 10-917-6;

- *Program Plan for the Development of Collapse Assessment and Mitigation Strategies for Existing Reinforced Concrete Buildings*, NIST GCR 10-917-7;

- *Evaluation of the FEMA P-695 Methodology for Quantification of Building Seismic Performance Factors*, NIST GCR 10-917-8;

- *Applicability of Nonlinear Multiple-Degree-of-Freedom Modeling for Design*, NIST GCR 10-917-9;

- *Research Plan for the Study of Seismic Behavior and Design of Deep, Slender Wide Flange Structural Steel Beam-Column Members,* NIST GCR 11-917-13; and,

- *Selecting and Scaling Earthquake Ground Motions for Performing Response-History Analyses,* NIST GCR 11-917-15.

EL is developing its in-house research capabilities in the earthquake engineering area. In 2012, a major step forward occurred with the acquisition and installation of a high performance multi-core computer system, with supporting software, that will facilitate rapid turn-around on performing nonlinear dynamic structural analysis. The in-house and extramural efforts are complementary, with numerous new products anticipated in 2013.

As described previously, in 2007, NIST awarded a major multi-year IDIQ research contract to the NEHRP Consultants Joint Venture (NCJV), a partnership of the Applied Technology Council (ATC) and the Consortium for University Research in Earthquake Engineering (CUREE). This has provided EL with significant opportunities to retain leading earthquake engineering practitioners and researchers to work on its projects. The NCJV is actively engaged in research on the tasks mentioned in this Program Description. The NCJV tasks are managed differently from in-house projects. NIST awards the NCJV tasks on a multi-year basis to provide complete products, whereas the in-house projects are all managed on an annual basis, with a zero-based budgeting philosophy that examines annual progress before decisions regarding new funding are made. This IDIQ contract expires at the end of 2012, and EL anticipates soliciting in 2013 competitively for accessing similar capabilities for a new five-year time period.

Recognition of EL: NIST GCR 09-917-3, *Seismic Design of Steel Special Moment Frames*, was awarded an *Excellence in Engineering Award* by the Structural Engineers Association of Northern California in 2010. The NEHRP Management/Program Analyst was awarded the 2011 EL Support Award in recognition of outstanding administrative support. The NEHRP Director was awarded the DoC Silver Medal in 2010.

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[i] http://www.nehrp.gov/about/PL108-360.htm

[ii] Earthquake Engineering Research Institute, *Securing Society Against Catastrophic Earthquake Losses: A Research and Outreach Plan in Earthquake Engineering*, January 2003

[iii] The EERI report projected losses in terms of 2003 dollars. These costs are estimated to range between $125B and $250B in 2012.

[iv] In the context of this program, resilience may be thought of as the capability of a community to develop the adaptive capacity, through mitigation and pre-disaster preparation, to maintain important community functions and recover quickly when a major disaster occurs. Source: see end note *vii*.

[v] *Strategic Plan for the National Earthquake Hazards Reduction Program, Fiscal Years 2009-2013*, October 2008

[vi] *National Preparedness*, Presidential Policy Directive/PPD-8, The White House, March 30, 2011

[vii] National Research Council, *National Earthquake Resilience: Research, Implementation, and Outreach*, 2011.

[viii] Applied Technology Council, *The Missing Piece: Improving Seismic Design and Construction Practices*, ATC 57, 2003

[ix] See end note *i*.

[x] http://www.gpo.gov/fdsys/pkg/BILLS-112hr3479ih/pdf/BILLS-112hr3479ih.pdf

[xi] http://www.gpo.gov/fdsys/pkg/BILLS-112s646is/pdf/BILLS-112s646is.pdf

[xii] NEHRP Advisory Committee on Earthquake Hazards Reduction, *Effectiveness of the National Earthquake Hazards Reduction Program*, May 2008

[xiii] See end note *v*.

[xiv] See end note *vii*.

[xv] See end note *viii*.

[xvi] American Society of Civil Engineers, *ASCE Standard, Minimum Design Loads for Buildings and Other Structures, ASCE/SEI 7-10*, 2010.

[xvii] A corporate partnership of the Applied Technology Council and the Consortium of Universities for Research in Earthquake Engineering.

[xviii] See end note *v*.

[xix] EL works in close partnership with FEMA in this research area.

[xx] *Research Plan for the Study of Seismic Behavior and Design of Deep, Slender Wide-Flange Structural Steel Beam-Column Members*, NIST GCR 11-917-13, 2001.

[xxi] *Research Required to Support Full Implementation of Performance-Based Seismic Design*, NIST GCR 09-917-2, NIST, 2009, see http://www.nehrp.gov/pdf/NISTGCR09-917-2.pdf .

[xxii] American Society of Civil Engineers, *ASCE Standard, Seismic Rehabilitation of Existing Buildings*, ASCE/SEI 41-06, 2007.

[xxiii] See end note *xvi*

[xxiv] Federal Emergency Management Agency, *NEHRP Recommended Seismic Provisions for New Buildings and Other Structures*, 2009 Edition, FEMA P-750 2009.

[xxv] http://www.nehrp.gov/pdf/SeismicWavesJun10.pdf

[xxvi] See end note *xxii*.

[xxvii] See end note *v*.

[xxviii] See end note *vii.*

[xxix] *Workshop Proceedings: NEHRP Workshop on Meeting the Challenges of Existing Buildings, Volume 1*, ATC-71, Applied Technology Council, 2008; and, *Prioritized Research for Reducing the Seismic Hazards of Existing Buildings*, ATC-73, Applied Technology Council, 2007.

[xxx] *Research Required to Support Full Implementation of Performance-Based Seismic Design*, NIST GCR 09-917-2, 2009.

[xxxi] American Lifelines Alliance, *Post-Earthquake Information Management System (PIMS) Scoping Study*, 2008.

[xxxii] http://www.nehrpscenario.org/ .

[xxxiii] http://www.nehrp.gov/library/clearinghouse.htm .

[xxxiv] *Standards of Seismic Safety for Existing Federally Owned and Leased Buildings, ICSSC Recommended Practice 8* (RP 8), NIST GCR 11-917-12.